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Crushing analysis of the industrial cage mill and the laboratory jaw crusher

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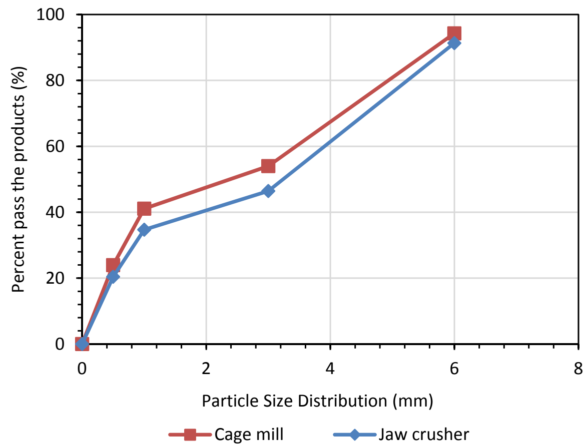
HIGHLIGHTS

- Industrial cage mill creates better mineral liberation of middling than the jaw crusher.
- Grinding the middle product with a cage mill results in a better yield than jaw crusher.
- The rate of fines produced through the jaw crusher is less than the cage mill.

GRAPHICAL ABSTRACT



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ABSTRACT

Many research studies have been conducted on the liberation of locked minerals using a crusher and comparing this device with the other devices. This paper reviews the liberation of middle coal by different methods of crushing force. In the Tabas coal washing plant, particles of 0.5-50 mm size are processed through the heavy media method (using 3 Tri-flo separators) and particles of 0-0.5 mm size are processed using the flotation method (using 6 column flotation cells). A Tri-flo separator with a diameter of 700 mm and the capacity of 120 tons per hour is used for the cleaning of 6-50 mm raw coal particles. The study was conducted using a laboratory jaw crusher and a cage mill with a specific comminution ratio, both crushing forces were analyzed with the same distribution and mechanism of production of fines. In this study, grading and washability characteristics of a representative sample of middle product were reviewed and the dimensions of the ash were measured for each section. Intermediate product crushing using a laboratory jaw crusher and an industrial cage mill were conducted at up to 5 mm size and 50 percent of final speed. The amount of coal released after each section grading was determined by a sinking and floating test for size +0.5 mm and release analysis and ash testing for smaller dimensions of -0.5, these tests were conducted for each section product dimension. The results indicated that utilizing a cage mill is more effective than a laboratory jaw crusher, resulting in 11-percent more yield with 12 ash. The rate of fines produced through the laboratory jaw crusher is less than the industrial cage mill.

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1. Introduction

Coal preparation in the late 1890's and early 1900's began in the United States. At that time, the coal separation process was conducted by hand and mechanical operations [1]. Over the past century, the role of coal and its importance in the world economy was remarkable. In 1860, coal was so important to the world that it allocated 60 percent of the total value of all minerals. However, with the arrival of oil and gas the use of coal as an alternative fuel in the world became rarer. Iran is ranked twenty-sixth in the world in terms of coal reserves, the largest of which are the Tabas reserves.

In the past, only coarse fragments of coal were recovered after extraction, and due to the lack of appropriate technologies small coal particles would be transferred into tailing damps. Later, the demand for a product with a uniform distribution particle size and the need for acceptable degrees of liberation in coal crushing caused coal crushing devices to be developed at the same rate as washing processes [2]. The initial load of coal washing plants is usually derived from underground and ground mines. Occasionally, a 10 inch coal might be extracted. In mineral processing plants the size reduction process is performed using crushers and mills [1]. The extraction method in the Tabas Parvadeh coal mines is underground mining. Because of the nature of mass and extraction method of coal, the size of extracted materials is different.

In comparison with the released metals, coal fines generated from coal have a relatively larger size. Controlling the size of coal fines in the crushing procedure would be very effective. The coal petrology of middle and raw coal has significant differences indicating there are noticeably different characteristics on their surfaces [7,8]. For coal mining and extraction coal should first be crushed, and a controlled crushed particle size would be useful to feed the processing plant. In addition, there is the need to use the right equipment to reduce the fines and to reduce the contact surface with rock minerals. To further develop the system in this paper we analyzed changes to the operating and systematic parameters and investigated the effect of the two parameters of known speed and added water.

Coal comminution is the final process of the grinding operation. The process in the comminution phase involves reduction of the particle size, impact, and abrasion. The main goal of crushing is to obtain the appropriate degree of liberation. The highest rate of energy consumption in the processing plant is attributed to crushing. In practice comminution is performed along with event impact, in which both free and locked particles are present. Among these types of particles, the locked particles are suitable for comminution. Impact creating on the border between mineral particles results in the most ideal situations. Many experts have studied and investigated the fracture mechanics for coal, which is a brittle and fragile material. Pressure, impact and cutting are the main steps in coal crushing devices. Middle product crushing in the Tabas coal washing plant is conducted using a cage mill. A cage mill is a rotating crushing system in which a multiple grinding plates moves in retrograde motion, and where the cages move together with the same speed but in the opposite direction. As the material is passed through the device and is crushed from one step to the next, the impact velocity increases. Preferably, coarser particles will be crushed. Figure 1 shows the structure in this device.

The material enters the internal cage through a slot. These devices are mainly used for brittle materials such as coal and salt. The main mechanism of crushing occurs in the cage mill [3]. The movement of particles can be controlled through design of the crushing rods in the device. By using more rows, more coal with a size of less than 75 micros is achievable. The mill size and design is based on impact in terms of feed parameters (volume of the sample and feed particle moisture), product parameters (shape and distribution), and some system parameters (rate of wear parts and specific machinery) [9].

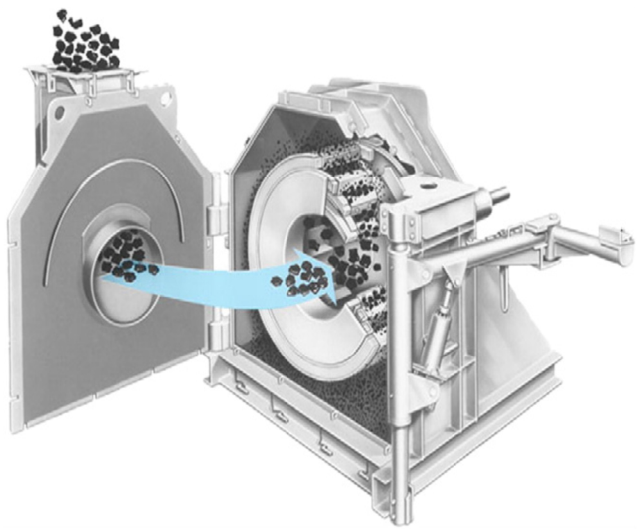


Fig. 1. Schematic of a cage mill and two cages [3].

Coal preparation plants generally do not reduce the size too much. Fractures in the mass of coal during processing result in the production of fines, depending on the nature of the coal and processing plant [4].

Gravity separation techniques are used for various materials such as sulfide minerals, e.g. galena, and coal in sizes smaller than 50 microns. The use of this method has increased in recent years because of the increased cost of chemicals necessary in the flotation operation, simplicity of installation, and low environmental pollution. Although these methods are known as gravity methods because of their special mass, classification of shape and dimension play important roles in these methods [11,12]. Analyses of sinking and floating are based on the floating particle density. Particles in the analyses of sinking and floating in each section consists of two even parts, namely ash and burnt material. The ratio of these two parts is important for calculation of the degree of liberation in coal. The degree of liberation related to the ash could be measured.

Nowadays, the demand for environment-friendly products, with respect to environmental regulations and requirements, has increased; in this case that refers to the recovery and quality of the product in relation to the coal distribution in the minerals [5]. Due to this coal concentrate production costs will increase because of the high costs of crushing. Nowadays, electrical disintegration (ED) equipment is a new technology for crushing coal. In this technology the failure mechanism of action is selective; however, they are not generally used due to the operational costs [10].

In the Tabas coal washing plant the cage mill is located in a key part of the plant, and its halt would affect the whole circuit break down. In the event of the necessity for extreme repairs of the cage mill, the plant's goal was to replace the cage mill with another device which has more availability and also produces less fine particles in the product. In this research a jaw crusher was selected to investigate the subject in batch scale. Finally, the purpose of crushing is to increase the liberation in a

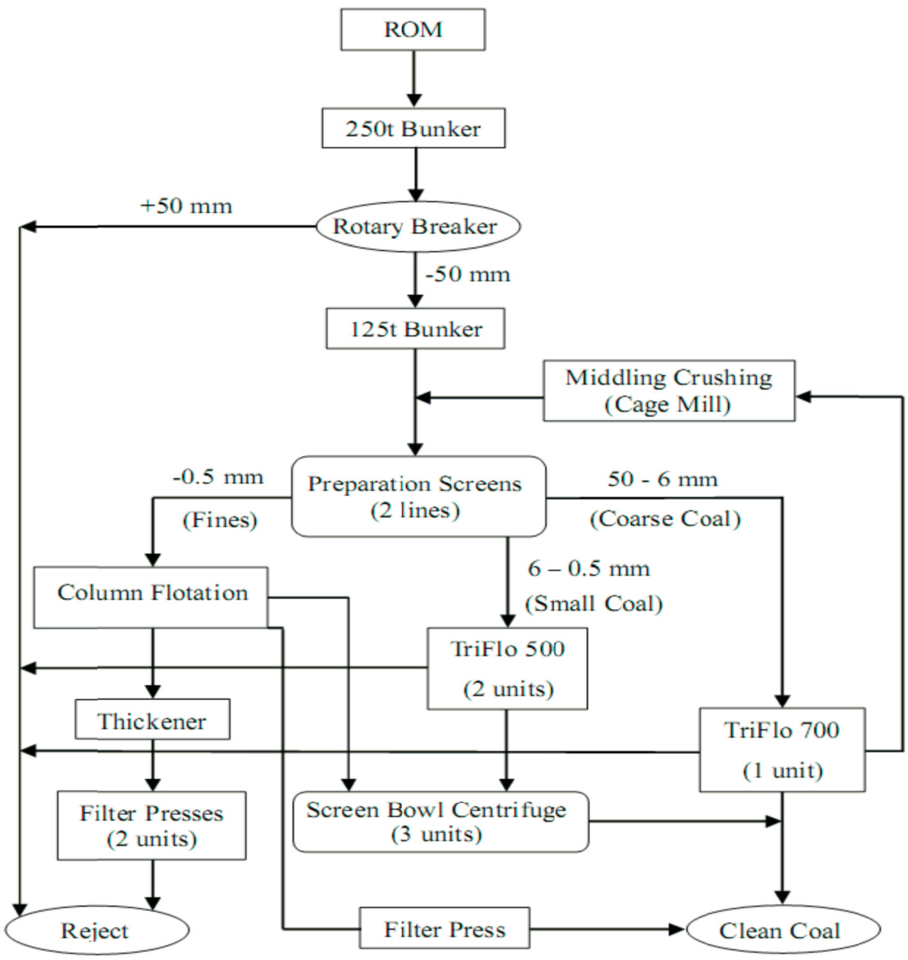


Fig. 2. The process flowsheet of the Tabas Coal Preparation Plant (TCPP) [13].

mineral with the minimum rate of size reduction. This goal needs selective fractures in coal. In this research, middle load crushing was conducted using a cage mill and jaw crusher with different force.

2. Material and methods

2.1. Sampling

The effect of size reduction in coal recovery can be expressed by the curved washability test capability. In this paper, liberation of middle coal using the industrial cage mill and laboratory jaw crusher were examined with the same degree of liberation according to the Tabas coal washing plant flow sheet (Figure 2).

According to the original plant design a Tri-flo 700 model of DWS700, which is used in the heavy media section for condensing the coal from the size of 6 to 50 mm, is used for two different densities in two separate parts of the plant. Each section consists of a cylindrical enclosure. The material ejected from the output 2 section comes out as middle material with 30-40 ash (Figure 3). With respect to the relatively high tonnages of this material in the Tabas coal washing circuit (30 ton per hour) appropriate grinding of coal and an increase in the degree of liberation will result in a reduction in the amount of waste of the valuable product. One of the sections includes the densities of +1.5-1.7 g/cm^3, and constitutes a 10 percent share of the total feed. The size of this section is usually less than 50 mm. With respect to theoretical criteria, 400 kg of sample were provided. The samples were collected in a flow middle load in a shift of 5 hours. In this study, crushing was examined on the middle load. Therefore, the analysis of a representative sample was conducted before and after grinding. The products with +0.5 mm were analyzed through sinking and floating as well as ash percentage. For -0.5 mm products, release analysis and ash percentage were conducted.

3. Results and disscusion

3.1. The middle coal crushing

Fluctuations in the size and difficulty of the feed are the most important factors in grinding circuit disruption. If there is an increase in the size or hardness feed, coarser grading will be achieved unless the feed is reduced. Grading and ash feed is shown in Table 1.

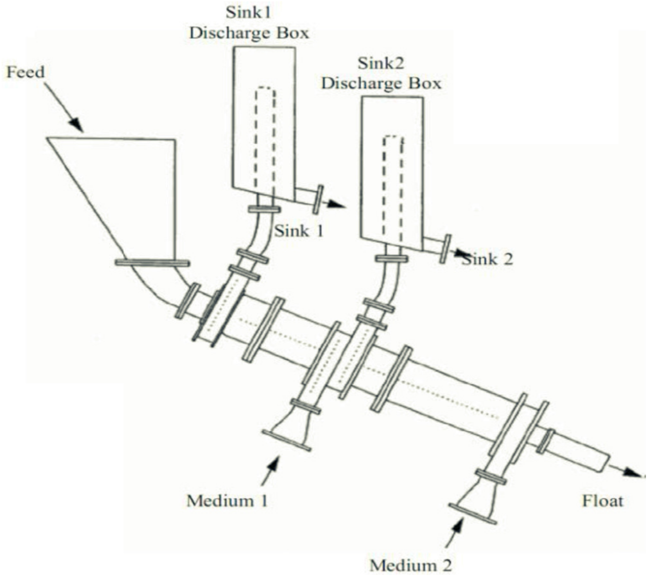


Fig. 3. Schematic diagram of a tri-flo separator [13].

As Table 1 shows, an increase in the size of minerals results in the increase in the ash percentage.

The cage mill model 40B2C4R with 4 cages and the jaw crusher model BM2 were used for crushing the middle load in the coal washing plant circuit. The cage mill and the jaw crusher were activated in the form of an open circuit. The sieve analysis is shown in Figure 4. According to this diagram, the two devices have almost the same liberation degrees.

3.2. Washability test of the middle product

Washability analysis of the middle product was investigated using yield-ash curves. The analysis of washability of crusher feed results are shown in Table 2.

According to the Table 2, there is a noticeable conflict between coal and waste in the coarser size. In this study, for ease of comparison between before and after

Table 1. Gradation and middle ash of the tri-flo separation in TCPP.

Size (mm)	W (%)	Ash (%)
(+50)	7.66	35.6
(+25-50)	10.7	36.7
(+12-25)	28.14	34.1
(+6-12)	26.2	35.7
(+3-6)	23.19	33.5
(-3)	4.11	38.3
Total	100	34.9

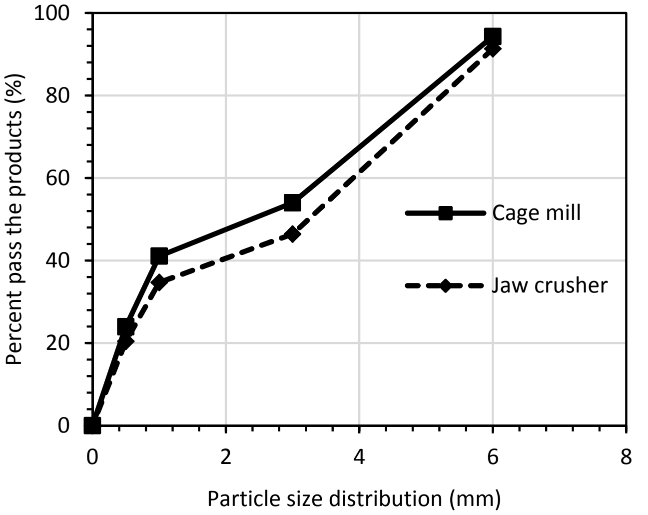


Fig. 4. Comparison of industrial cage mill and the laboratory jaw crusher for the degree of liberation of the middle coal after crushing.

crushing conditions in each sample of the concentrates, the middle and waste are separated and compared with each other. As can be seen in the table, 94 percent of the total middle sample consists of middle product with 33.83 ash, which is considered a high share. The purpose of grinding is mainly to reduce this section.

3.3. Washability analysis of products

Crushed products were granulated into 5 classes: +6, (-6+3), (-3+1), (-1-0.5) and -0.5 mm. The sinking and floating test was conducted in 6 different fractions. The Washability test Chart showed that the industrial cage mill resulted in the best yield (Figure 5).

For products with different forces, final yield was achieved with 12 ash. Liberation of middle products after crushing with the different devises is shown in

Table 2. Washability test results of the middle load of the tri-flo separation in TCPP.

Feed	W (%)	Ash (%)
Yield (%)	1	12
Coal	0.6	10.59
Middle	94.72	33.83
Reject	4.68	60.13
Total	100	34.92
Coarse (%)	78.32	
Small (%)	21.68	
Fine (%)	0	
Total (%)	100	

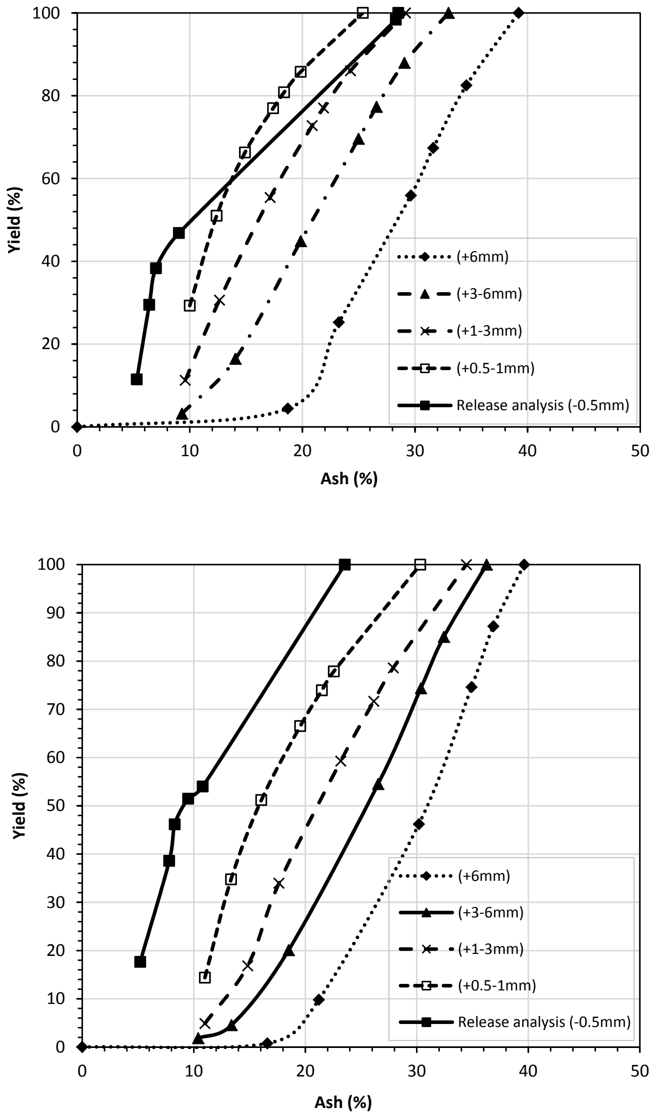


Fig. 5. Diagram of the sink-float analysis of the industrial cage mill and the laboratory jaw crusher.

Table 3. The base was +0.5 mm, as it was for feed. Floating 1.3 and 1.4 were considered as coal and sinking 1.8 was considered as waste. And the density of 1.5 and 1.7 was considered as middle. The table shows the contribution of each size with respect to building screening of the coal washing plant and what share after crushing will be allocated to each part of the plant (Figure 6).

As can be seen, if ash 12 is chosen as the criterion for the comparison of different force of devises yield after crushing, the yield would increase using the cage mill while the jaw crusher results in a decrease in the yield because of the excessive grinding of materials. This in turn leads to an increase in ash; but the laboratory jaw crusher yield is reduced because of the lack of material and fines production. Thus, we conclude that grinding

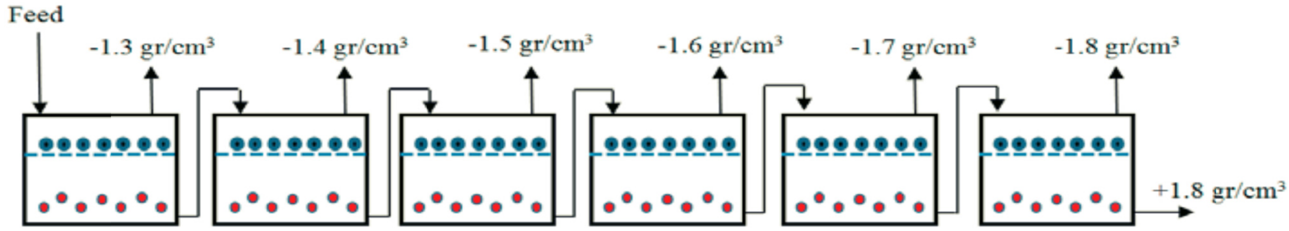


Fig. 6. Schematic diagram of the sink-float experiment [13].

Table 3. Washability test middle samples results and the amount of concentrates, middle and waste in the middle materials (after crushing).

	Jaw crusher		Cage mill	
	W (%)	Ash (%)	W (%)	Ash (%)
Yield (%)	17.5	12	28.5	12
Coal	19.5	11.3	30.5	11.5
Middle	66.0	33.9	58.5	34.9
Reject	14.3	57.2	10.9	59.3
Total	100	32.8	100	30.5
Coarse (%)	9.09		5.7	
Small (%)	69.3		70.3	
Fine (%)	21.5		23.9	
Total (%)	100		100	

the middle product with an industrial cage mill results in the best yield rate. This would cause the release rate to increase to about 30.5 percent of coal ash, which in turn results in a 3 percent increase in the total yield of the plant. The fluctuation of ash products is due to fluctuation of the tri-Flo device.

3.4. Mechanism of fine

Milled products were categorized in dimensions of -0.5 mm in 4 classes: + 500, (-500+300), (-300+150), (-150+75) and -75 microns. The -75 micron products were considered as fine, results of which are shown in Table 4.

Table 4. Determine the amount of fine in the middle materials (after crushing with different forces).

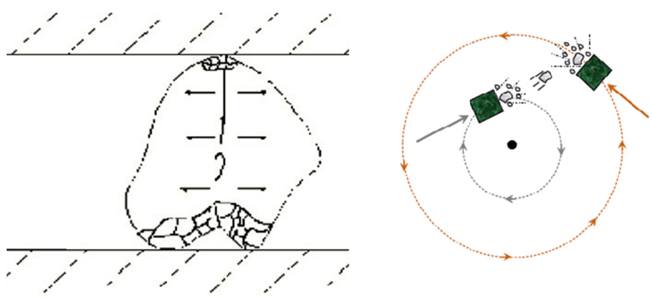
	Cage mill		Jaw crusher	
	W (%)	Ash (%)	W (%)	Ash (%)
Fine	4.89	25.60	4.01	25.1
Ash (total)	30.5		32.8	

It is observed that increasing the ash decreases the amount of produced fine in line. At different forces, the rate of fine produced in the jaw crusher is less than the industrial cage mill. The crushing sequences in the jaw crusher were less than the cage mill. Thus, the particles were exposed to less impact; therefore, they produce less fine particles.

3.4. Fracture mechanism of these two methods

The freedom degree of the products comminuted by the jaw crusher and the cage mill are contrasted under similar size distribution. Combined effects of crushing, splitting and bending are applied to realize size reduction by the jaw crusher. In these fragmentation forces, crushing is the dominant force which urges particles to be separated through boundaries. When an irregular particle is crushed by crushing the product falls into two distinct size ranges: coarse particles resulting from the induced tensile failure and fines produced from either compressive failure near the points of loading or by shear at projections as shown in Figure 7a [7].

Nevertheless, impact is the main force utilized by cage mills. The particles are then struck by the subsequent cage rows before exiting through the bottom of the mill, contact with materials and stress concentration causes mineral liberating through the interface as shown in Figure 7b.



(a) **(b)**

Fig. 7. Size reduction mechanism of (a) jaw crushing and (b) cage milling [3,7].

4. Conclusion

By contrasting the effects of different kinds of fragmentation forces on mineral liberation, the industrial cage mill which utilizes crushing as the main force creates better mineral liberation of middling than the laboratory jaw crusher with pressure as its main force.

We conclude that grinding the middle product with a cage mill results in a better yield rate than the laboratory jaw crusher. This would cause the release rate to increase to about 30.5% of coal ash, which in turn results in a 3% increase in the total yield of the plant.

In addition, the rate of fines produced through the laboratory jaw crusher is less than the industrial cage mill.

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